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NAVSEA's Computational and Experimental Mechanics Laboratory (CEML) at NUWC Division Newport

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The Naval Undersea Warfare Center (NUWC) Division Newport's Computational and Experimental Mechanics Laboratory (CEML) provides a unique Simulation Based Design (SBD) facility for the rapid, cost-effective design and production of components, subsystems and systems for undersea vehicles. State-of-the-art computer hardware and software are integrated to provide optimal modeling and simulation capabilities in a concurrent engineering environment.

The facility is staffed by 20 designers and analysts, many with advanced degrees and extensive experience in systems engineering. The facility provides a Center-wide resource that supports NUWC's Common Product Development Process (CPDP) initiative. The CPDP integrates the product development function in matrix structure to maximize synergy across product lines. In addition, the fully networked architecture encourages collaboration with outside experts from the academic, military and industrial communities. For test and evaluation and to streamline the flow of data into the design process, the laboratory provides unique test capabilities consisting of NUWC's acoustic wind tunnel, anechoic chamber, electric motor test facility, high-speed water tunnel, and the chemistry and materials test facilities.

The SBD Laboratory, combining a diverse, experienced group of people, tools and equipment to effectively address and solve Navy technical problems

Models and simulations are developed in the SBD Laboratory, while testing takes place in both CEML land-based facilities and in the field. Mechanical subsystems can be evaluated in the laboratory using the on-site test facilities in conjunction with a broad array of specialized instruments and fixturing. Stereolithography is often utilized for the rapid prototyping to construct physical models within a day. Stereolithography models are produced in NUWC's machine shop using the paperless electronic transfer of design information.

The stereolithography process itself seamlessly builds a dimensionally accurate physical model using a laser in a photopolymer bath. This model provides the basis for a low-cost investment casting process to produce a production-quality hardware prototype for assessment in the CEML facilities. The design model can also transition directly into software for the production of training documentation, tools and interactive simulations.

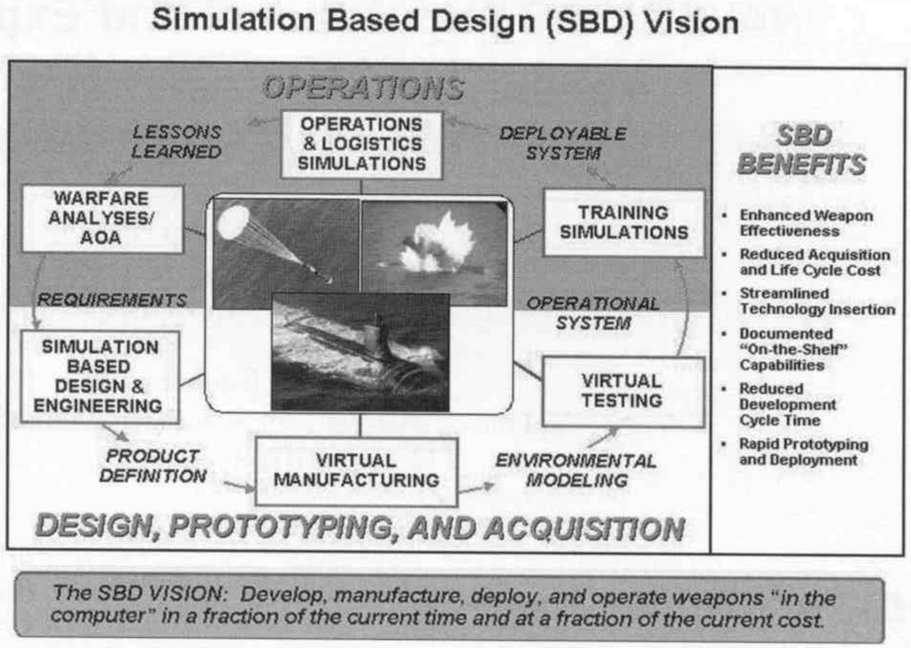
Advantages of SBD

The SBD environment resulted from NUWC's desire to capitalize on the integration of research and development into the undersea warfare systems acquisition, deployment, and life-cycle support process and to preserve this expertise through storing the proven processes, mathematical models, and body of knowledge in a common database that is accessible to future developers. SBD allows for the concurrent engineering of systems and continuous process improvement as new products are developed within the facility and the experience gained is included in the expanded body of knowledge.

SBD is a totally associative environment that effectively implements concurrent engineering principles and provides the following well-documented advantages:

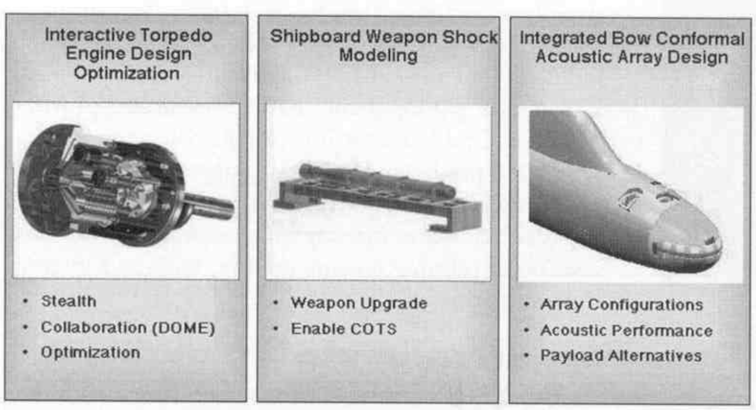
- Reduced development time of 25-30 percent
- Reduced development cost of 30-40 percent
- Decreased cycle time for engineering changes of 40-50 percent
- Improvement in reliability of 12-15 percent.

SBD supports Simulation-Based Acquisition (SBA) by providing a virtual prototyping capability that accelerates the early phases of the acquisition process. Extensive use of validated experimental data in a simulated environment allows the development team to create a well-balanced design that considers performance, producibility, supportability and life-cycle costs. A further benefit is the availability of information created during the development process that can be reapplied for the production and support of the weapon system. Design information can be directly integrated into production of the weapon system components and used in the acquisition of logistic support elements, including test equipment and multimedia material for interactive training courses.



Simulation Based Design (SBD) Laboratory vision

The laboratory supports the core design and analysis activities required to enable the information-based development of highly effective and inherently affordable Navy weapon systems. The undersea weapon design process begins with modeling and the analysis of high-payoff system concepts. Solid models are generated for candidate systems, which serve as the foundation for the modeling and simulation of critical operational characteristics and the detailed design of subsystem components. Tools used are summarized in the box on page 11. These virtual representations of the fielded systems are leveraged throughout the product life cycle to increase the efficiency of vehicle operations and support activities; to aid in diagnosis and resolution of engineering issues; and to support the development of future system upgrades.



Project-specific examples of Simulation-Based Design/Acquisition (SBD/A)

Sponsors

The laboratory is supported by NUWC Division, Newport, by the Office of Naval Research (ONR) and by the Naval Sea

Design Tools Available at NUWC's CEML

Available design tools include a wide range of the latest software products. The table below shows an extensive library of software programs that enable the laboratory to accomplish its cutting-edge assignments efficiently and effectively.

ANALYTICAL TOOLS	
Stress/Strain:	ABAQUS, COSMOS, ANSYS, NASTRAN, BOSOR, customized tools
Shock and Vibration:	ABAQUS Explicit, LS DYNA, USA, HyperMesh
Acoustic Radiation:	AutoSea, SARA, customized tools
Fluids:	PMARC, FastShip, Fluent, customized tools
Thermal:	ABAQUS, ANSYS, SDRC
Electromagnetic:	EMASS, ANSYS, Mentor Graphics
DESIGN TOOLS	
Mechanical:	SDRC I-Deas Master Series 2-D drafting, 3-D solid modeling, kinematics, sheet metal, cabling, design optimization (stress & strain only); AutoCad; Intergraph; Pro Engineer
EMPIRICAL DATABASE	
Embedded in the design environment in an extensive measurements database of naval undersea vehicles from the acoustic wind tunnel, anechoic chamber, acoustic tank facility, hydrodynamic facilities, chemistry and materials test facilities, and the ADCAP shock database.	
PROTOTYPING	
Numerical control machining	
Stereolithography model generation for investment casting	
Mold design	
ANIMATION/ VISUALIZATION	
Animation of FEA/Modal Analysis Data	
Interactive visualization of hardware assembly and operation	
Output animations to videotape, laptops, CD-ROM	

Typical applications include: conceptual design; system structural, acoustic, thermal and hydrodynamic analysis; detailed design; and prototype fabrication and testing.

Systems Command (NAVSEA). ONR and NAVSEA are the primary customers of laboratory resources. The two agencies state their needs in broad agency announcements, and the laboratory responds with proposals for funding on an individual project basis.

ONR, in particular, funds the laboratory for the Undersea Weapon Design and Optimization (UWDO) program, which is focused on the development and deployment of the models, tools and architecture to execute effective SBD. The CEML also supports industry through dual-use agreements, providing commercial access to unique test and analysis capabilities.

Efficient test and evaluation

Test and evaluation of physical prototypes has historically been a critical component of the undersea weapon development process. In an era of declining military budgets, the significant expense associated with the manufacture and testing of physical hardware dictates the use of innovative approaches to support testing and evaluation activities. The SBD laboratory actively employs rapid prototyping methodologies to support system fabrication and integration and is an integral component of the NUWC CEML, which provides both the computational resources and land-based test facilities required for the development of both evolutionary and revolutionary undersea weapon systems.

Prototype components can be fabricated quickly using the paperless fabrication process leveraging on-site laser stereolithography and computer numeric control machinery, and then used to support both component and system-level testing in the CEML. At-sea operation testing of prototype systems also is performed at local and remote range facilities. The process leads to the rapid, cost-effective development and transition of prototypes that have a high probability of meeting system requirements with minimal rework.

Major projects

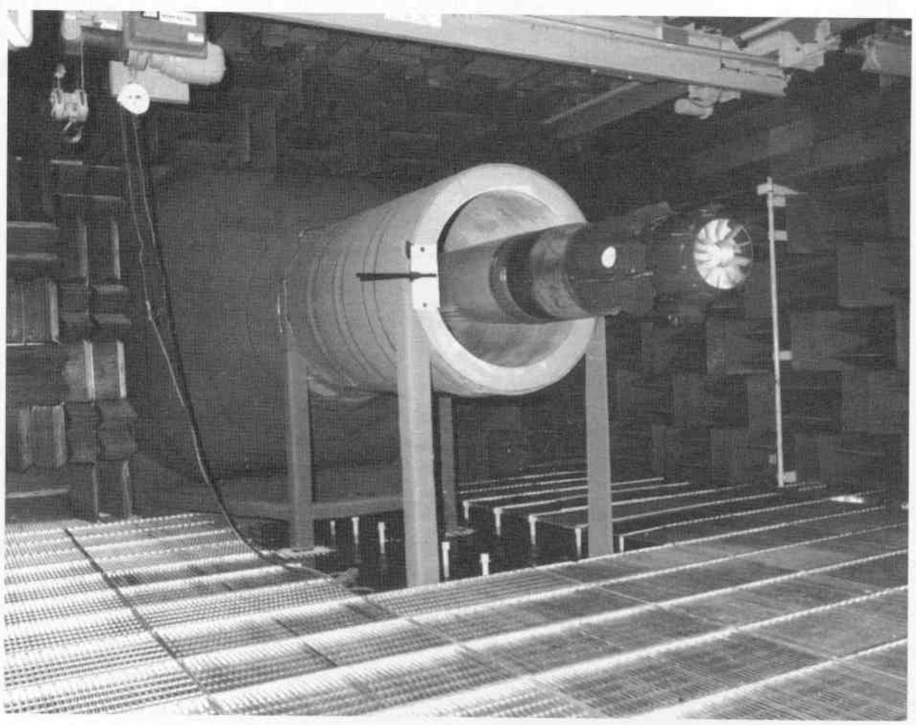
The SBD Laboratory is supporting the ONR UWDO program, which is focused on the development of a web-based environment to support the timely development of successful and cost-effective undersea weapon systems. This program is sponsored by Dr. Kam Ng (ONR 333) and seeks to revolutionize the undersea weapon technology and product development process through the enhanced use of validated high-fidelity modeling and simulation tools. The UWDO program leverages recent advances in high-performance computing and communications to create a computational environment that enables the multi-disciplinary optimization of complex, technologically advanced weapon systems prior to design commitment. An essential element of the UWDO program that is closely aligned with ongoing initiatives in the operations and support arena is its strong emphasis on achieving the continual transition of increasingly capable systems to the fleet while concurrently reducing the total ownership cost of fielded weapon systems.

The range of work being accomplished at the SBD laboratory indicates the significant and wide breadth of hardware/software capabilities, professional expertise and systems applications that are integrated in the CEML. The Lightweight Hybrid Torpedo (LHT) project *(see box, page 13)* provides insight into how SBD accomplishes its mission.

■ *The LHT Buoyancy Shell Section (BSS).* An example of how the SBD process works toward the production of workable prototypes can be found with the LHT/BSS. The mission was to provide a buoyancy section for the LHT exercise configuration to ensure post-run vehicle recovery and to reduce turnaround costs; to develop a system with increased capability over existing systems while reducing the life-cycle cost of operation and ownership by at least 50 percent; and to demonstrate the proof-of-concept and in-water operation of a full-scale prototype within 15 months. Upon completion of the design process, the model was electronically integrated with the existing LHT solid model design database to ensure accurate and up-to-date configuration integration and control.

■ *The ADCAP Shock Program.* The SBD Laboratory is currently supporting several critical Navy programs that include technology development for next-generation undersea weapon systems such as undersea vehicles, anti-torpedo torpedoes and supercavitating weapon systems. Ongoing efforts that focused on the shock hardening of legacy weapon systems provide a concrete example of the synergistic interaction between modeling and simulation activities and real-world testing. Engineering modifications are developed employing high-fidelity design and analysis tools, and virtual experiments are performed prior to performance of physical testing. Subsequent testing has a high probability of success resulting from the increased maturity of the design and the insight afforded the experimentalist by the modeling and simulation predictions. Additionally, the testing itself serves to validate and improve the core predictive capability through which the system was developed.

A specific application was to ensure that current ADCAP shock qualification status was not degraded by the introduction of Mod 6 upgrades. Full system-level simulations of the ADCAP Mod 5 and Mod 6 torpedo in the SSN 688 and the SSN 21 stowage environments were developed in the weapon SBD environment. Models were applied to develop, evaluate and tune shock-hardening design concepts prior to building conceptual hardware. The shock database

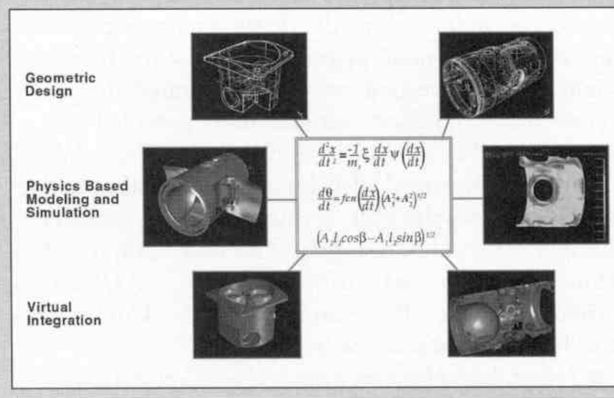


Torpedo propulsor testing in the Computational and Experimental Mechanics Laboratory (CEML) acoustic wind tunnel from historical underwater explosive testing was captured within the SBD environment to provide model excitations and validation data.

System models were developed with a modular construction to facilitate extension for evaluating incremental upgrades. Access to the modular models

How the SBD Process Results in Prototypes:

Example of the Lightweight Hybrid Torpedo (LHT) Buoyancy Shell Section (BSS)



Physics-based development of the Buoyancy Shell Section (BSS) for the Lightweight Hybrid Torpedo (LHT)

The broad goal of the Lightweight Hybrid Torpedo (LHT)/Buoyancy Shell Section (BSS) project was to provide a buoyancy section for the LHT exercise configuration to ensure post-run vehicle recovery and to reduce turnaround and life-cycle costs of operation and ownership by at least 50 percent. How did the SBD Laboratory succeed in its mission?

The conceptual design process was aided by an on-line database so that historical concepts and designs could be called up and evaluated for applicability to current requirements. An immediate down-selection from a proven design database provided a robust design concept.

Integrated physics-based analysis codes and computational engines were used to support system-level structural evaluation of performance. Analysis and testing were performed on the actual design model, eliminating geometry recreation and assuring fully associative design changes between the design and the analysis.

High-fidelity validated models supported system optimization with minimal factors of safety to maximize strength-to-weight ratios and system capacity. Integrated tools provided continuous updates on mechanical parameters including weight, fuel capacity, center of gravity and center of buoyancy to ensure that convergence to a viable design option was achieved.

The successful development of a prototype BSS required the integration of hydrodynamic and vehicle dynamic modeling tools within the SBD environment to evaluate the complex system behavior required for buoyancy system development at operating speeds (see figure). The solid model provided immediate evaluation of system fitment, component integration, and ease of assembly while automatically highlighting mechanical interference.

These tools provided an envelope of preliminary design options to overlay with mission requirements. Design optimization was applied to minimize total ownership cost, primarily through an order of magnitude reduction in the expense for section turnaround.

Based on this *a priori* effort, a concept emerged from the preliminary design review down-selection that was well within mission requirement boundaries. Detailed design and modeling was then performed to support design optimization, fitment and integration studies and manufacturing optimization. Direct communication with a stereolithography system for building plastic prototypes from a photosensitive elastomeric polymer was used to produce a low-cost physical mock-up, which aided the concept visualization and fitment and integration studies.

Stereolithography prototypes were then used in an investment casting process to provide a cast prototype without a requirement for a detailed design package requiring months of additional labor. Design files were electronically transmitted to the manufacturer, resulting in a paperless manufacturing process. The prototype was then exercised in land-based test facilities to confirm system performance without costly in-water runs. Upon completion of the design process, the model was electronically integrated with the existing LHT solid model design database to ensure accurate, up-to-date configuration integration and control. ❑

and historical shock database supports acquisition reform by allowing immediate insertion of commercial-off-the-shelf (COTS) hardware to assess survivability prior to qualification testing.

■ *Heavyweight Torpedo.* State-of-the-art SBD tool sets were introduced into the development of prototype and incremental upgrades to existing heavyweight torpedo weapon systems. Integrated design, analysis and simulation software tools provided system designs that met all system requirements while achieving compressed development schedules and providing life-cycle cost savings. Specific projects included the Half-Length Torpedo, Improved Submarine-Launched Mobile Mine, ADCAP Torpedo Shock Program and the Common Broadband Acoustic Sonar System.

■ *Towed Array Handling System.* Operation and maintenance of handling systems for towed arrays currently have high visibility within the U.S. Navy. The primary area of interest is the extension of working life of the array by improving its design and minimizing damage inflicted by the handling system. This goal can be most efficiently addressed following the SBD paradigm.

■ *MANTA Program.* All solid modeling for the initial development of the MANTA unmanned undersea vehicle was coordinated in the laboratory. Using a paperless design strategy, the SBD approach for the MANTA Test Vehicle included finite element analysis, material testing, three-dimensional solid modeling and CNC tooling, all of which led to fabrication of composite material parts whose molds were created directly from electronic files. Models were shared electronically among production team members, including Seaman Composites in Gulfport, Mississippi. Through this process, Seaman was able to flawlessly execute the prototype fabrication. A similar effort is now underway for the Large Broadband Variable Depth Sonar towed array housing.

■ *Submarine Sail.* The Next Generation Submarine Sail project was initiated as a potential technology enhancement for the New SSN (NSSN). The project involved a multidisciplined approach to characterize and assess the notional sail candidates in terms of hydrodynamics, hydroacoustics, target strength, radiated noise, structural integrity under various loading conditions and other characteristics pertinent to submarine sails. A number of scale models were designed and fabricated using the SBD and rapid prototyping tools. Concepts were evaluated quickly and cost effectively in the acoustic wind tunnel, leading to an optimal design concept.

New laboratory features

In addition to the capabilities developed and applied to the BSS program, added capabilities for improved prototyping and product acquisition are constantly being developed. Recent enhancements to the SBD environment include:

■ *Real-time collaborative design* with designers and analysts working at geographically dispersed sites, exchanging design and analysis results and design modifications in a single engineering environment with shared control.

■ *Design data integration software* that allows solid models from multiple design software products to be integrated in a single model for design review and integration studies.

■ *A tool that provides direct translation* from the design database to a multimedia training tool. This tool provides a capability to study and follow the procedures for system buildup, maintenance and teardown in an interactive, dynamic solid model environment. A dynamic navigator enables the user to query the tool to provide two-dimensional drawings or part lists directly to the screen.

■ *Database management tools* have been introduced to coordinate team participation. In conjunction with this task, classified and sensitive unclassified websites have been designed and deployed to facilitate team interaction. Certificate authentication has been incorporated to meet the requirements for Internet transmission of sensitive program data. Intelligent web navigation has been introduced to maximize site effectiveness.

Future directions

The ONR has funded many of the current efforts in defining the SBD environment, developing toolsets, and demonstrating the feasibility of associative system development and data transfer between different applications. ONR is particularly interested in developing a realistic appraisal of emerging technologies. This capability will be most useful in determining the research and development investment strategy that ONR should pursue to be responsive to the needs of the future Navy. Future system enhancements will provide the following functionality:

■ *Enhancement of physics-based analysis tools.* The current specialized physics-based analysis tools developed for 6.1 (basic) and 6.2 (applied) research and development applications must be enhanced to support usage by the general community.

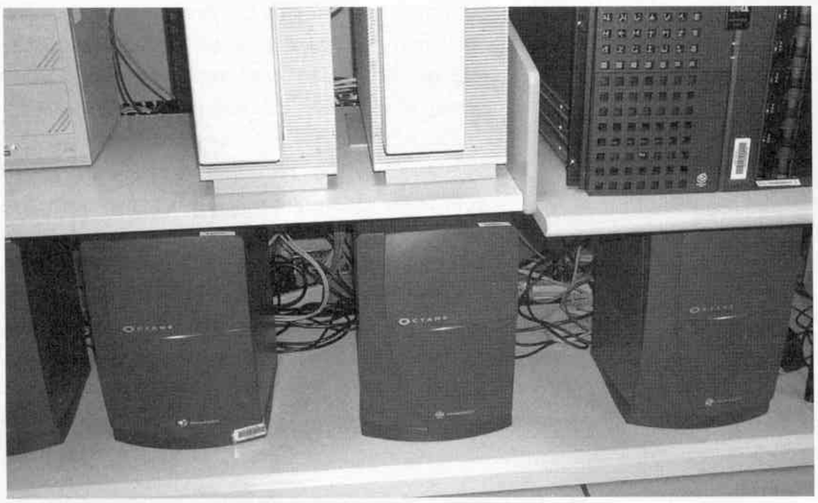
■ *Graphical user interfaces.* This requires the development of user-friendly interfaces and documentation to transition analysis tools from developers to users.

■ *Acquisition support.* Codes must be integrated within the 6.3 (Advanced Technology Demonstration) and 6.4 (Advanced Development) environments to support technology transition to the acquisition process.

■ *Driving design.* The existing toolset must be integrated into the design process so that information used for, or created by, the model can be used seamlessly with other analysis tools. Off-line tools create delays and may add cost as a result of data reformatting requirements.

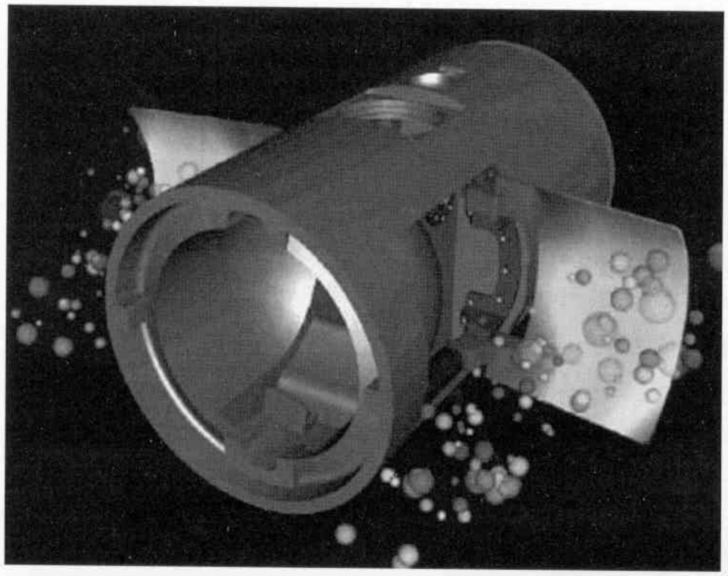
■ *Correlation of functional and physical attributes.* The design library must contain a full set of functional as well as physical attributes so that candidate systems can be readily derived from a functional baseline that is created during the requirements phase. This capability would greatly accelerate the creation of viable candidates from available databases of existing and new technology options.

■ *Total ownership cost.* Cost will be a major element to be considered during design tradeoffs. Cost will be treated as an independent variable in applying life-cycle cost models to cost-effectiveness analysis. Every action in the workflow will include cost and operational considerations, whether in the design, production or support analysis. The cost of each activity also will be tracked, so that confidence in estimating and delivering projects within cost can be assured. The cost evaluation will determine the risks in meeting budget and schedule requirements.



Key computer hardware used at NAVSEA's Computational and Experimental Mechanics Laboratory (CEML) at NUWC Division, Newport: the Dell Power Edge 6300/Oracle 81 database (top) with high-end Silicon Graphics NT workstations and the ONYX2 Supercomputer (bottom)

■ *Production and support system.* The object information developed in electronic format during the design and testing phase will be used to create the production and support system. For example, the



Simulated operation of the Lightweight Hybrid Torpedo (LHT) Buoyancy Shell Section (BSS) system showing displacement results as developed by the Simulation Based Design (SBD) Laboratory, NUWC Division Newport

computer-aided design (CAD) drawings and other object data will be used to create the numerical control tapes for production, the artwork for circuit boards, interactive training for operation and maintenance, spare parts lists, special tools required and facilities layout. The main disciplines involved in the development will have input early in the design and be sensitive to the potential impact on life cycle support.

Turn-of-the-century assessment

The development and application of the SBD system has been validated by its application to system design and prototyping. The LHT BSS prototype system development and demonstration, for example, was accomplished in 15 months, a reduction of more than 50 percent compared with traditional methodologies. Projected section turnaround costs have been drastically reduced. The initial design was integrated with limited re-engineering or re-manufacturing and has met all of its performance goals tested to date. The product database supported acquisition and will continue to support the system life cycle.

NUWC welcomes the opportunity to apply its SBD system knowledge to other programs and looks forward to a future of enhanced capabilities and new directions with new partners. It has a state-of-the-art facility in the CEML to fulfill its mission. ❑

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